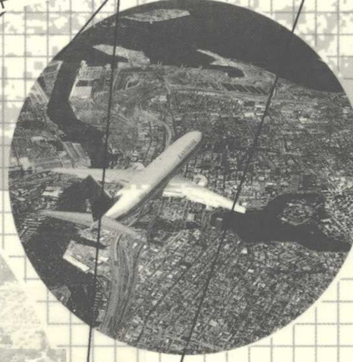
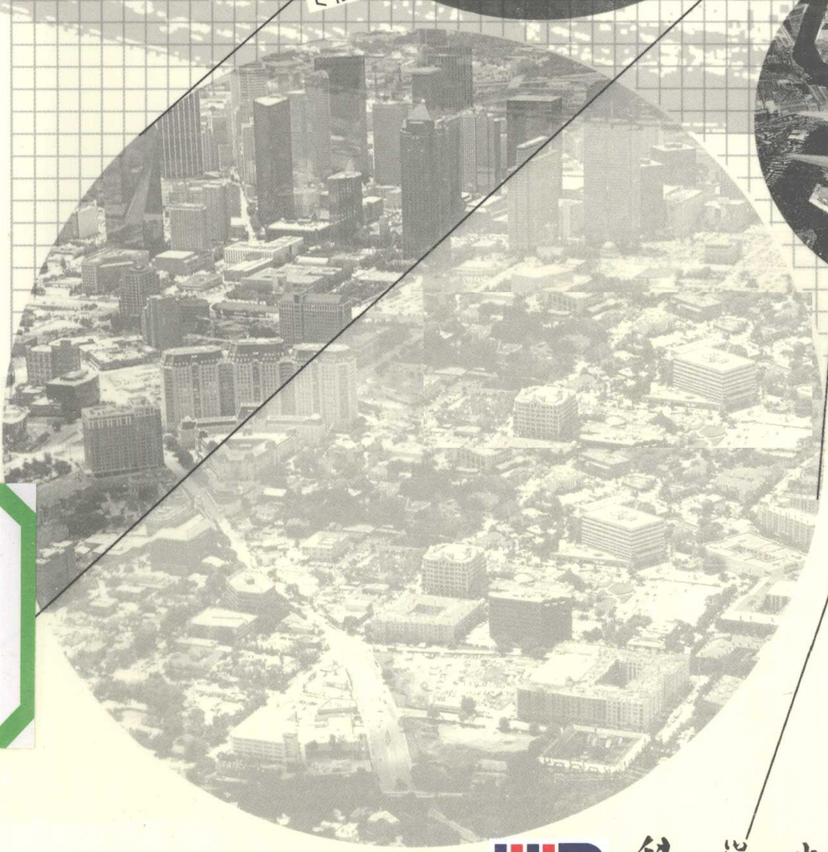
航空摄影光学镜头“Russar”图集

Atlas of Aerial Photographic Lenses “Russar”

〔俄〕纳·阿·阿佳里曹娃 编著
魏光辉 译





科学出版社
www.sciencep.com

内 容 简 介

本图册汇集了世界著名俄罗斯学者、广角航空摄影光学的奠基者，鲁西诺夫教授主持研究、设计的几乎全部航摄光学镜头“Russar”。图册给出了每种镜头的光学结构图及其主要像差曲线，附表则详尽列出每种镜头的设计参数(透镜曲率半径、光学材料等)。

本图册适用于从事光学系统设计与计算的专家、工程技术人员、大学教师和研究生，以及有兴趣于航空摄影的光学爱好者。

图书在版编目(CIP)数据

航空摄影光学镜头“Russar”图集＝Atlas of Aerial Photographic Lenses “Russar”/(俄罗斯)纳・阿・阿佳里曹娃编著；魏光辉译. —北京：科学出版社，2010

ISBN 978-7-03-027590-5

Ⅰ.①航… Ⅱ.①纳… ②魏… Ⅲ.①航空摄影-光学透镜-摄影镜头-图集 Ⅳ.①TB869-64

中国版本图书馆 CIP 数据核字(2010)第 088857 号

责任编辑：王志欣　耿建业 / 责任校对：郑金红

责任印制：赵博 / 封面设计：耕者设计工作室

科 学 出 版 社 出版

北京东黄城根北街 16 号

邮政编码：100717

http://www.sciencep.com

天时彩色印刷有限公司印刷

科学出版社发行　各地新华书店经销

*

2010 年 5 月第 一 版　开本：B5(720×1000)

2010 年 5 月第一次印刷　印张：14

印数：1—1 000　字数：258 000

定价：180.00 元

(如有印装质量问题，我社负责调换)

前　言

本图集详细介绍了航空摄影光学镜头“鲁萨尔(Russar)”。鲁萨尔(Russar)系列航摄光学镜头由米哈衣尔·米哈衣诺维奇·鲁西诺夫教授(1909～2004)领导的学术团队所设计，其中最具代表性的一百具镜头在本书出版公布，以此纪念鲁西诺夫教授一百周年诞辰。

北京理工大学魏光辉教授组织、筹划了本图册的出版。魏光辉熟知鲁西诺夫教授，私交甚密。他虽然未成为教授的直接弟子，但可以认为是间接学生，非常仰慕鲁西诺夫教授在航空摄影光学领域取得的卓越成就。20 世纪 90 年代(1989 年前后)，鲁西诺夫教授曾多次受邀在北京和哈尔滨的高等学校、研究所讲学，展示了由苏联大地测量、航空摄影与制图学中央科学研究院列宁格勒光学实验室(Optical Laboratory, Central Scientific Research Institute of Surveying, Aerial Photography and Cartography)高级研究员纳·阿·阿佳里曹娃博士编辑出版的航空摄影光学镜头图集。虽然这一图集只给出了各种镜头的光学结构图，没有给出各个镜头的光学参数，但是它让看到这本镜头集的中国学者惊奇、激动，产生了获知其详细参数、进行学习和应用的愿望。本图集的出版实现了这一的愿望。

本图集包含航空摄影光学镜头一百具；不仅给出每个镜头的光学系统结构图，而且在紧随的附表中给出其详细的设计参数(组成透镜的几何光学参数和光学材料参数)与像差曲线。所以，本图集不仅呈现了广角航空摄影光学的科学发展历程，而且，更为重要的是其学术价值。图集中每个镜头的表列数据将有助于我国光学学者通过本书学习鲁西诺夫学派的学术思想，研究他们设计和发展“Russar”航摄镜头的方法特点。更进一步，我国学者可借鉴本书中的数据，采用简单的比例缩放或者通过改变已有镜头的某些参数(增减透镜、改换透镜材料等)并通过电脑程序核算，设计出适用于新需求的光学镜头。

这里首先简要介绍鲁西诺夫教授率领他的学派发展广角航空摄影光学镜头的创造历程。鲁西诺夫教授是俄罗斯几何光学系统设计和系统计算学术领域的奠基者、俄罗斯学派的导师。鲁西诺夫教授于 1934 年设计了世界上第一个广角航空摄影镜头“Liar-6”，1935 年设计出“Russar-1”，它们使航摄测地发生了真正的革命。用广角航摄光学镜头实施大地测绘以取代此前世界各国通常采用的将“分片”照相和多镜头照相法所获取的照片加以拼接，从而获取大面积测地图片的方法，极大地简化并加速了航摄测地的作业过程。

1939～1940 年，基于鲁西诺夫教授所发明的系统，他的团队设计了“Russar-21～Russar-24”。此系列光学镜头的视场角达 122°～140°，具有极佳的像场照度分布，

其像场中心与周边的照度比值甚至可以优于朗伯定律(Lambert's law)。这一系列 Russar 光学镜头曾经申请了美国、英国和法国专利并应用于瑞典威尔德公司(Wild Company)的航摄装置样机。"Russar-29"是其中最具代表性的产品化光学镜头,其焦距 $f'=70$mm,视场角 $2\omega=122°$。此镜头的发明和应用实现了 20 世纪 50 年代中以 1∶100000(十万分之一)的比例对全苏联国土的测绘。利用"Russar-29"进行的测绘不仅快捷,而且其高分辨测绘精度也是当时全世界前所未有的。

航摄光学镜头的视场角大于 120°之后,引发出研究此类光学镜头像场内光强分布的理论,并由此设计出具有理想像场光强分布的新型镜头光学系统。鲁西诺夫教授及其团队为此所创造的新型光学系统是在常规镜头光学系统的入射端增添一个负透镜,其内表面为深度非球面,且其放大率远小于 1。利用这一新光学系统方案设计了超广角航摄镜头"Russar-32"(1947)、"Russar-38"(1953),其焦距 $f'=36$mm,视场角 $2\omega=148°$。最普及应用的镜头是"Russar-62",其焦距 $f'=50$mm,视场角 $2\omega=136°$,1965 年研制成功。

上述独特性能的航摄光学镜头由于其优异的广角特性、更加均匀的像场光强分布(像场边缘照度可达像场中心照度的 23%),极高的成像质量,而举世无比。它们的实用价值则是其一次航拍能够完成大面积航摄影任务的可能性,因而在航摄大地测绘领域得到广泛应用。

航摄地图测绘步入中等和超大比例尺范围对光学镜头的成像质量和量度特性均大幅度地提高了要求。因此,为完善"Russar-29"航摄光学镜头进行了两个方向的改进:①使镜头中间部分的构成更加复杂化;②将镜头前端的新月形负透镜与主体部分分开。按照上述第一种改进方向曾于 1973 年成功设计出"Russar-71"物镜,其焦距 $f'=100$mm,视场角 $2\omega=103°$。按照第二种改进方向曾设计出"Russar-73"及"Russar-79",其焦距 $f'=70$mm, $2\omega=120°$。

在本图集中我们还收集了"Russar"镜头系列中一些具有专门用途的镜头。例如专用于外层空间摄影的长焦距物镜"Russar-77"($f'=3$m)、"Russar-78"($f'=4.5$m);用于处理航摄图片的洗印放大器镜头"Russar-70^{RF}";用于大屏幕投影的高亮度(大相对孔径)广角投影物镜"Russar-82^{PR}",其焦距 $f'=100$mm,50mm;特别应提及的是广角反射-透射式航摄镜头"Russar-66^{ML}"和"Russar-69^{ML}",其焦距 $f'=70$mm,视场角 $2\omega=120°$,光学系统中采用了二阶非球面反射面,由此获得了近衍射极限的成像质量。本图册中最后几组镜头中最具代表性者当属航摄镜头"Russar-93"($f'=100$mm, $2\omega=100°$),被增大的相对孔径为 1∶4.5。它采用了独特的非对称光学结构,从而严密地消除了畸变。

鲁西诺夫教授一生从事广角摄影物镜的发明和完善,他在这一领域的先行者地位和取得的成果为(俄罗斯)国内外所公认。1972 年他获得法国自然科学院以 E. Losseda 命名的国际科学奖。1982 年鲁西诺夫教授以其第三代、第四代和第五代测地制图光学镜头的研发成果获苏联最高级政府奖——列宁科学与技术奖。与

此同时，他的学生与同事，纳·阿·阿佳里曹娃也获得列宁科学与技术奖。

本图集由纳·阿·阿佳里曹娃博士提供了全部资料，包括镜头光学系统、图表数据、像差曲线，并编辑成本书手稿。魏光辉教授负责将原俄文书稿译成中英文并促成本书在中国出版。深信，本图册将有益于从事光学系统设计、计算的专家，以及对此有兴趣的高校教师、研究生和光学爱好者。

北京理工大学光电学院李林教授审阅了全部书稿，提出了有益的修改与建议，特此致谢。

编　者

2010.2

Foreword

This Atlas of aerial photographic lenses "Russar" designed by the supervision of Professor Mikhail Mikhailovich Rusinov(1909～2004) has been issued in connection with his 100th birth anniversary celebrated in 2009.

The author of the project and initiator of this Atlas is Wei Guanghui, Professor of Beijing Institute of Technology. He knew M. M. Rusinov personally, and had an intimate knowledge of his works in the area of aerial photographic optics by the Atlas which had been prepqred and compiled by the senior research fellow of the Central Scientific Research Institute of Surverying, Cartography and Aerial Photography(ЦНИИГА и К), N. A. Agal'tsova. Besides, the Atlas was demonstrated by the Chinese engineer in 1989 in Harbin where M. M. Rusinov and N. A. Agal'tsova gave lectures.

The Atlas is supplemented with new optial schematics of the aerial photographic objective lenses. The main difference lies in the tables attached in the Appendix which specify the design data of all lenses. Hence, this Atlas not only represents a scientific interest that makes it possible to trace the evolution of wideangle aerial photographic optics, but also has a great applicative value as the use of tabular data of this. That lens may help(by simple proportional recalculation or by some modifications of optical schematic with aid of recent achievements, i. e. , PC-based analysis programs, and new optical glasses, etc.) to produce a lens with new performance capabilities corresponding to the specific tasks imposed on the developers.

The following is several key points of the creative biography of M. M. Rusinov, one of the most distinguished optic scholars of Russia. M. M. Rusinov is the founder of the scientific school of optical computing in the area of composition of differently-purposed optic systems. He is the author of the first wide-angle aerial photographic lenses "Liar-6"(1934) and "Russar-1"(1935) in the world which made a real revolution in cartography of the earth surface. Instead of patchworks and pictures mounted of images made by many aero-photocameras, it became possible for the experts to receive photographs with wide angular coverage. This has significantly speeded up and facilitated compilation of topographic maps.

In 1939～1940, wide-angle aerial photographic lenses "Russar-21～Russar-24" were developed based on the scheme invented by M. M. Rusinov. These lenses had the angular field of view ranging from 122° to 140°and provided significantly better light distribution in the field of vision comparing to that of the Lambert's law. The optical scheme of these "Russar" lenses has been patented in the Great Britain, USA, and France. It was used as a prototype for Aviogon lenses of the Wild Company (Switzerland). The most marketable lens of the like schematic lens was "Russar-29" with focal length $f' = 70$mm and angular field of view $2\omega = 122°$. The invention of this lens made it possible to complete mapping of all USSR territory in scale 1 :100000 by the midst of the 1950s. This was accomplished not only fast enough but also with high resolution quality that could not have been achieved before.

Enlargement of the view filed of that aerial photographic lenses above 120° called for further development of the light distribution theory and development of new lens structurs. This new design featured the installation in front of the lens of a negative lens with a deep inner aspheric surface and magnification ratio significantly lower than one. This new scheme was used for development of super wide-angle aerial photographic lenses "Russar-32" (1947) and "Russar-38" (1953), with $f'=36$mm and $2\omega=148°$. The most popular was lens "Russar-62" with $f'=50$mm and $2\omega=136°$ developed in 1965.

This unique lens was second to none in the world practice due to its outstanding wide angle properties and more uniform light distribution (off-axis illumination is 23% of the illumination in the centre) with considerably high image quality. Its main advantage lies in the possibility to capture large areas with only one shot. That is why it was widely used in aerial photography for geologic delineation.

The transition to middle-scaled and large-scaled cartography techniques required a sharp improvement of both representational and gauging properties of aerial photos. Modification of "Russar-29" lens series has been carried out in two directions, 1) by development of more sophisticated core component, and 2) by separation of the exterior negative meniscus (caps). Following the first direction, lens "Russar-71" ($f' = 100$mm and $2\omega = 103°$) developed in 1973 was the best design work. As to the second direction, the most distinguished were lenses "Russar-67", "Russar-73" and "Russar-79" with $f'=70$mm and $2\omega=120°$.

The Atlas also contains some schemes of special-purpose "Russar" lenses. For example, long telephoto lenses "Russar-77" ($f' = 3$m) and "Russar-78" ($f' = 4.5$m) have been designed for space/satellite observations. Reproduction lens "Russar-70^{RF}" was used in a photo transformer for processing aerial photos.

Wide-angle and high D/f' projection lenses "Russar-82^{PR}" with focal lengths 100mm and 50mm are designed for projection of transparencies to large screens. Wide-angle catadioptric aerial photographic lenses "Russar-66^{ML}" and "Russar-69^{ML}", with $f'=70$mm and $2\omega=120°$, are a kind of special case as they make use of aspheric specular surfaces of the second order by virtue of which images have received practically diffraction limited quality. One of the last lenses shown in the Atlas is worthy as well. It is aerial photographic lens "Russar-93" ($f'=100$mm and $2\omega=100°$) with an enlarged aperture ratio 1 : 4. 5. This lens has a specific scheme of asymmetric type but, at the same time, it is a strictly distortion-corrected lens.

Invention and modification of wide angle aerial photographic lenses were the lifework of Mikhail Mikhailovich Rusinov. The priority and significance of his works in this area has been recognized abroad as well. In 1972, he was honoured with the E. Losseda international award of the French Academy of Sciences. In 1982, M. M. Rusinov(Research Director) received the highest government decoration in the USSR, Lenin Prize in Science and Technology, for development of lenses of the third, forth and fifth generations used in cartography. At the same time, N. A. Agal'tsova, his follower and colleague, also became the Lenin Prize winner.

The Atlas has been compiled by N. A. Agal'tsova (schemes, diagrams, graphics, appendix, and foreword) and Wei Guang hui (translation into English, editorial and publishing issues). We hope that the Atlas will be of great use and interest for experts dealing with design and development of optic systems, university teachers and undergraduates.

Authers of this book are grateful to Professor Li Lin of Optical Electronics College, Beijing Institute of Technology. He attentively read and revised the manuscript of this book and gave useful comments and suggestions.

缩写及符号表
(Abbreviations and Symbols Table)

Astigm.	astigmatism　像散
Aspher.	aspherical　非球形
A. d.	aperture diaphragm　孔径光阑
chrom. aber.	chromatic aberation　色差
C	spectral line of $\lambda_C=656.2$nm $\lambda_C=656.2$nm 光谱线
C'	spectral line of $\lambda_{C'}=644$nm $\lambda_{C'}=644$nm 光谱线
d	air separation between component lenses 组成透镜之间的空气间隔
D	spectral line of $\lambda_D=589.6$nm $\lambda_D=589.6$nm 光谱线
e	spectral line of $\lambda_e=546$nm $\lambda_e=546$nm 光谱线
f'	focal length(effective) 名义焦距(后主面至后焦点之间的距离)
F	spectral line of $\lambda_F=486.1$nm $\lambda_F=486.1$nm 光谱线
F'	spectral line of $\lambda_{F'}=480$nm $\lambda_{F'}=480$nm 光谱线
h	hight of parallel entrance ray 平行入射光线高度
ML	mirro-lens composited(lens) 反射镜-透镜组成的物镜
n	non-spherical(lens) 具有非球面组成透镜的物镜
n_C	refractive index of spectral line $\lambda_C=656.2$nm $\lambda_C=656.2$nm 红光谱线折射率
n_D	refractive index of Natrium spectral line $\lambda_D=589.3$nm 钠黄光($\lambda_D=589.3$nm)折射率
n_F	refractive index of spectral line $\lambda_F=486.1$ nm

	$\lambda_F=486.1$ nm 蓝光谱线折射率
PR	projection(lens) 投影镜头
r	curvature radius of spherical surfaces of lenses 透镜球面曲率半径
RF	reproductive photo-transformer(lens) 洗印放大器镜头
Spher. aber.	spherical aberation 球差
$S'_{F'}$	second vertex focal length 后截距(物镜最后一个球面顶点至后焦点的距离)
x	concentrical(lens) 具有中心对称结构的物镜
y'_{pr}	image hight($y'_{pr}=f'\times\tan\omega$)of principal ray 主光线像高
Z_S	sagittal focal plane 弧矢焦面
Z_t	tangential focal plane 子午焦面
ν_D	Abbe number, $\nu_D=\dfrac{n_D-1}{n_E-n_C}$ 阿贝数,光学材料色散 n_F-n_C 的倒数表示
ϕ_D	(1)aperture diameter of lenses 透镜的通光孔径 (2)diameter of A. d. 孔径光阑的直径
ω	half field anqle of view 半视场角(视场边缘光线与光轴之间的夹角)

目　　录

航空摄影光学镜头“Russar”图集

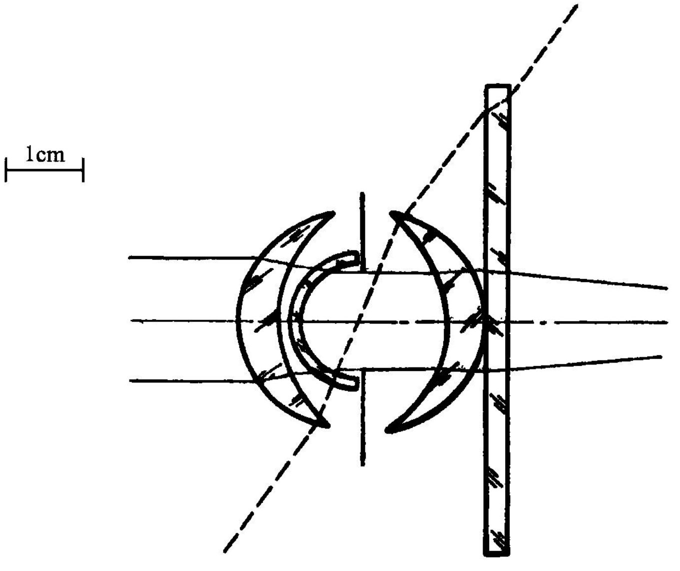
Atlas of Aerial Photographic Lenses “Russar”

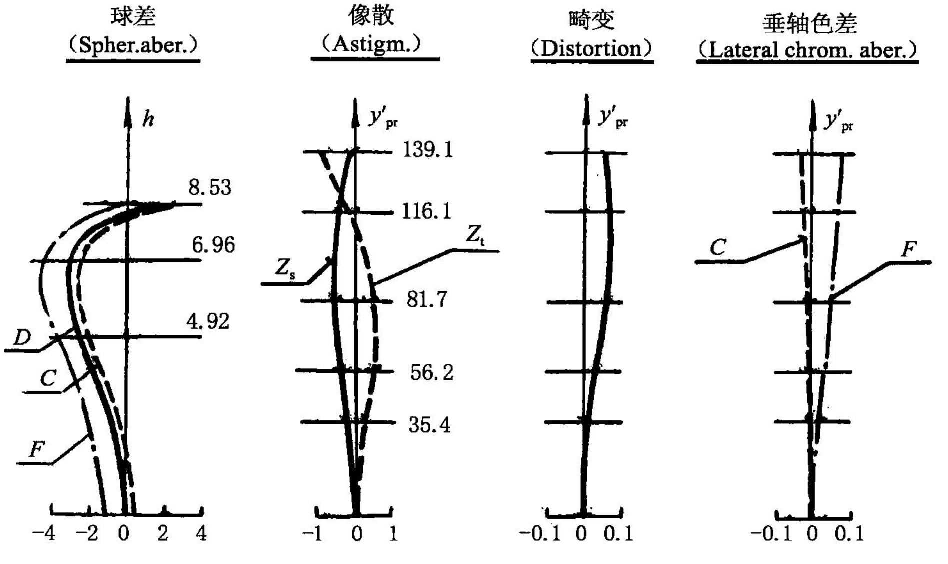
〔俄〕纳·阿·阿佳里曹娃　编著
魏光辉　译

科 学 出 版 社
北 京

"Russar-1"物镜
(Objective Lens "Russar-1")

$f'=97.335$ $S'_{F'}=75.499$ $2\omega=110°$ $D/f'=1:5.7$





"Russar-1"镜头结构参数
(Constructive Dates of "Russar-1")

表 1
(Table 1)

透镜表面序号 (Surface No.)	r	d	n_D	ν_D	玻璃牌号 (Sort of glass)	ϕ_D
1	15.00					29.58
		5.0	1.5100	63.35	K3	
2	18.535					29.68
		1.4	1			
3	9.73					19.30
		1.59	1.6475	33.86	TF1	
4	8.162					16.26
		19.31	1			
5	−18.535					29.18
		5.0	1.5100	63.35	K3	
6	−15.00					29.42
		0.0	1			
7	∞					61.42
		2.8	1.5163	64.05	K8	
8	∞					64.98

$f'=97.335$； $S'_{F'}=75.499$

孔径光阑距第 4 表面 8.16mm，直径 $\phi_D=13.08$mm

(A. d. at 8.16mm from the 4th surface, $\phi_D=13.08$mm)

"Russar-2"物镜
(Objective Lens "Russar-2")

$f'=99.843 \quad S'_{F'}=68.410 \quad 2\omega=110° \quad D/f'=1:5$